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Crop-tree Thinning of Western Larch in Southeastern British Columbia: 30-year Results

by
C.F. Thompson

BC
Ministry of Forests

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SUMMARY

A crop-tree thinning was conducted in a mid-slope, 31-year-old stand of western larch (*Larix occidentalis* Nutt.) in the East Kootenays of British Columbia. Four radii of clearance were used; control, 2.4, 3.6, and 4.8 m. Initial tree sizes ranged from 2.5 to 15.0 cm DBH.

After 30 years the diameter, basal area, and volume growth response were proportional to the degree of spacing and the initial tree size. The response lasted for 25 years, but growth has declined dramatically in all treatments in the last 5 years. A number of potential causes of the decline are suggested.

The magnitude of this response is consistent with that found in other thinning studies in larch. The comparison shows that early thinning, before crown lift occurs, will maximize the growth response. At 31 years, this stand was too old for maximum response.

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INTRODUCTION

In the dry and transition climatic regions of British Columbia, western larch (*Larix occidentalis* Nutt.) typically regenerates after fire in mixed, dense, almost even-aged stands, with scattered veterans. In such stands, larch rarely achieves its potential growth because of excessive stand density (Schmidt *et al.* 1976). As a result, timber productivity and the productivity of other resource values (particularly ungulate habitat) are depressed.

Given the limited distribution of the species, few studies have looked at the effect of spacing. This is unfortunate, since within its range, larch is a species of potentially high productivity, both biologically and economically.

High stand density has been shown to affect the growth of larch as early as 9 years (Schmidt 1966, 1978). Other studies have examined spacing in a 33-year-old stand (Seidel 1971, 1977, 1982, 1987), a 50-year-old stand (Roe and Schmidt 1965; Lowery and Schmidt 1967; Cole 1984), and a 55-year-old stand (Seidel 1975, 1980). Although the spacing strategies adopted in each study differ, the general conclusions are unanimous in supporting the importance of early spacing. While a diameter growth response can be achieved by spacing at any age, often more volume is lost by spacing after about 25 years than can be compensated for by an increase in growth on the remaining crop trees (Schmidt *et al.* 1976).

In all cases, the best individual tree growth response was produced by the largest trees, at wide spacings, but the maximum volume per hectare production was at close spacings.

Although spacing at an early age produces the greatest effect, the question of spacing older larch stands often arises. This report examines the first 30 years of a spacing study in an older stand of larch in southeastern British Columbia. Results from this project at 5, 10, and 25 years were reported by Illingworth (1964) and Thompson (1969; 1984[1]).

PROJECT DESCRIPTION

The project was established in 1958 in a mixed stand of fire origin, on a moderate slope on the south side of Perry Creek, near Cranbrook (49° 34′N, 115° 56′W) in southeastern British Columbia (Figure 1). The plots are on a north to northeasterly aspect at an elevation of 1130 m. Average western larch site index of the site is 25 m at 100 years (Hegyi *et al.* 1979). At the time of spacing, the stand was estimated to be 31 years old. The stand was a mixture, with larch as the principal component. Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) was a major component and lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) a minor component. All three species formed an essentially even-aged main stand, with an irregularly distributed, scattered overstory mainly of larch, but with some Douglas-fir veterans. The main stand was very irregular, with densities ranging from 1090 to 38 550 stems per hectare and an average density of 5290 stems per hectare.

The project lies on a zonal site within the Interior Douglas-fir Biogeoclimatic Subzone, IDFg3 variant.[2] The ecosystem association is Spirea–Calamagrostis.

The study is laid out in a randomized complete block design. In all, 120 trees were selected, with 20 in each of six diameter classes (2.5, 5.0, 7.5, 10, 12.5, and 15.0 cm). Treatments were randomly assigned to five trees in each diameter class. The treatments were: clearance to radii of 2.4, 3.6, and 4.8 m and a no-treatment control. Clearing involved the removal of all trees and shrubs within the specified radius. In some cases, because of the irregularity of the stocking, clearance to the prescribed radius resulted in an effective opening that was larger than the prescribed radius.

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[1] Thompson. C.F. 1984. EP 511. Crop-tree thinning of western larch. Progress report 3A. B.C. For. Serv. Res. Br. Intern. Rep., Mimeo.

[2] Utzig, G.F., P.G. Comeau, D.L. Macdonald, M.V. Ketcheson, T.F. Braumandl, A.R. Warner, and G.W. Still. 1986. A field guide for identification and interpretation of ecosystems in the Nelson Forest Region. 2nd revision. B.C. Min. For., Nelson.

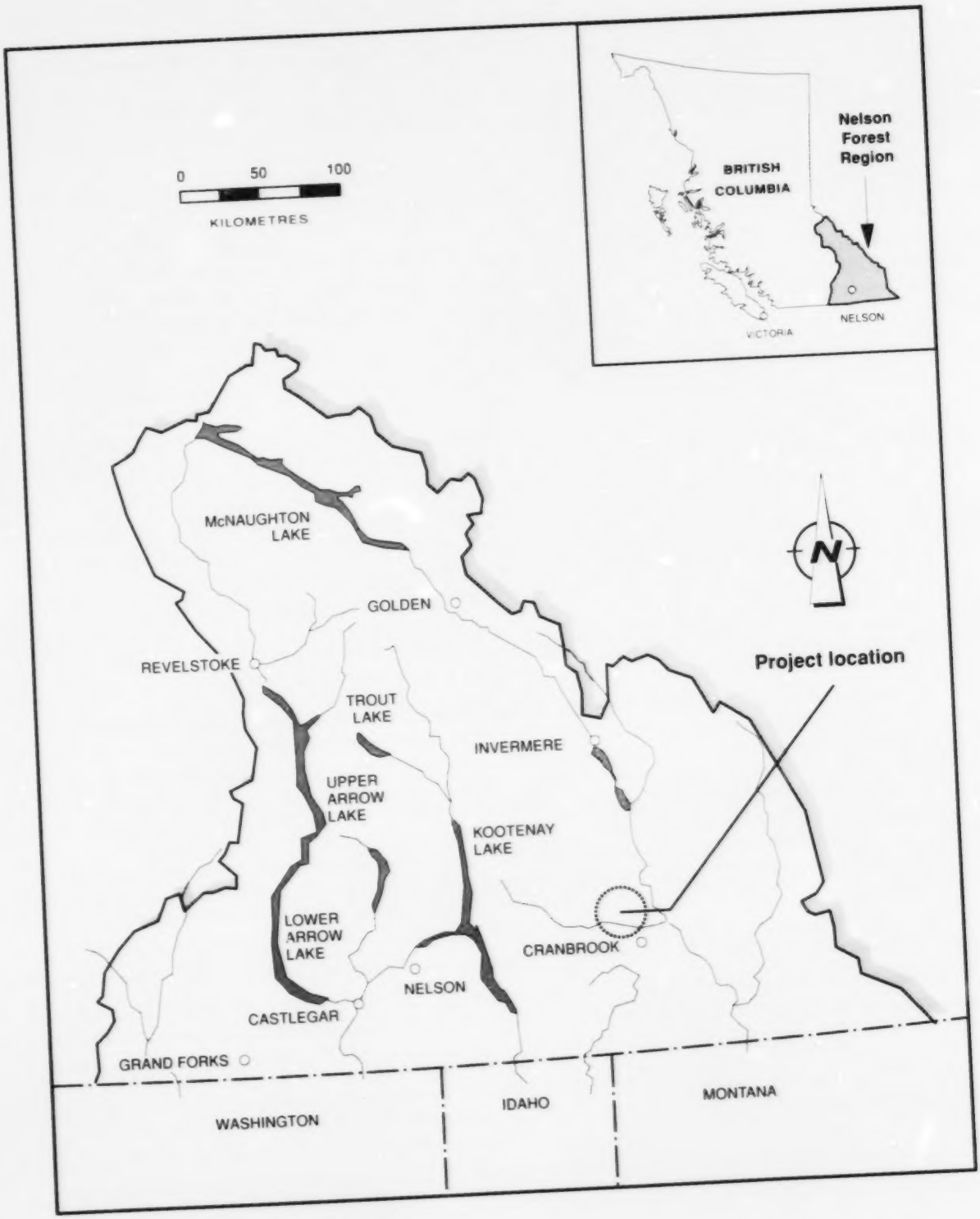

FIGURE 1. Approximate project location.

Although the selected trees were described as being "of good form, dominant or codominant and not less than thirty feet from each other or from the edge of the stand,"[3] the dominant or codominant requirement, at least in the smaller diameter classes, was not strictly adhered to. From our observations of the remaining stumps, there also appears to have been no major attempt to ensure that crop trees chosen had equal competitive stress before spacing.

MEASUREMENTS AND ANALYSIS

Diameter at breast height (DBH) and total height (H) were measured for each crop tree at 5-year intervals since 1958. Diameters were measured over bark at 1.37 m with a diameter tape. Height was measured to the growing tip, with a chain and clinometer. Since establishment, all measurements have been taken in Canadian yard-pound units and converted to the SI units (Système international d'unités).

For the purposes of analysis, the spacing treatments were quantified as the amount of growing space (m^2) occupied by an individual crop tree. For the three spacing treatments, growing space was taken to be a circular area centred on the crop tree, with a radius equal to half the radius of the cleared plot. For the control treatment, the growing space was based on a reconstruction done in 1980 of the number of stems per hectare surrounding each crop tree in 1958. The four growing space levels tested in this trial are: control (which averages 1.89 m^2), 4.67, 10.51, and 18.65 m^2.

In the past 30 years, six trees have died; five were in the 2.5 and 5.0 cm diameter classes. All but two trees were in the narrowest spacings (control and 4.67 m^2 growing space). One tree in the 7.5 cm diameter class was killed by a bear. In addition, five trees are now suffering from snow press; this damage is confined to the two smallest diameter classes, and the three closest spacings. Because of the low incidence, no analysis of damage and mortality was attempted.

All trees were included in the analysis, which consisted primarily of descriptive statistics. In addition, periodic diameter increment for each 5-year period was compared with the average diameter increment, following Bickerstaff's (1946) technique. To model diameter, height, and merchantable volume, all possible regressions were performed. Dependent and independent variables were evaluated untransformed, and as square root and logarithmic transformations. Promising models were compared through the use of un-transformed coefficients of determination, and by examination of plots of residuals against both predicted values and all independent variables.

RESULTS

The Effect of Spacing on Diameter

Average diameters in 1958 and 1988 are shown by initial diameter class and treatment in Table 1.

Tree diameter growth increased with increasing diameter class and with the intensity of spacing (Figures 2 and 3). The largest trees in the widest spacing grew by 10.1 cm in 30 years, compared with 3.6 cm for the smaller trees at the same spacing and with 5.1 cm for the same sized trees in the control. There was a smaller increase between diameter classes 4 and 6 than there was between diameter classes 1 and 3 (Figure 4).

Periodic diameter growth compared to the average diameter growth rate began to decline 15 years after treatment (1973), with all treatments in decline after 20 years (1978) (Figure 5). The rate of decline accelerated after 1983, with all treatments showing negative relative diameter growth by 1988. The most acute reductions occurred in the control and the closest spacing.

[3] Stewart, M. 1958. EP 511. Crop-tree thinning of western larch. Working plan. B.C. For. Serv. Res. Br. Intern. Rep., Mimeo.

TABLE 1. Summary tree statistics (mean ± SE) for each diameter class

	Diameter class (cm)					
	2.5	5.0	7.5	10.0	12.5	15.0
CONTROL						
Diameter (cm) 1958	3.5 ± 0.1	4.6 ± 0.4	8.2 ± 0.2	10.3 ± 0.3	12.5 ± 0.2	15.3 ± 0.3
Diameter (cm) 1988	5.6 ± 0.5	8.3 ± 0.4	12.4 ± 0.6	15.6 ± 0.6	17.5 ± 0.7	20.4 ± 0.5
Number (1988)	5	2	5	5	5	5
Height (m) 1958	6.3 ± 0.3	6.2 ± 0.7	8.9 ± 0.2	10.5 ± 0.6	12.1 ± 0.6	13.8 ± 0.5
Height (m) 1988	7.7 ± 0.8	11.0 ± 0.3	14.7 ± 0.6	16.6 ± 0.3	16.7 ± 0.9	19.0 ± 0.8
Number (1988)	4	2	5	5	5	5
GROWING SPACE 4.67 m²						
Diameter (cm) 1958	3.5 ± 0.2	5.4 ± 0.3	7.6 ± 0.3	10.0 ± 0.2	12.8 ± 0.1	16.3 ± 0.3
Diameter (cm) 1988	7.7 ± 0.4	9.9 ± 0.6	12.5 ± 0.7	17.1 ± 0.8	19.0 ± 0.9	24.0 ± 0.7
Number (1988)	4	5	5	5	5	5
Height (m) 1958	6.3 ± 0.4	7.7 ± 0.6	8.5 ± 0.3	9.8 ± 0.5	11.9 ± 0.1	14.8 ± 0.5
Height (m) 1988	9.8 ± 0.7	12.6 ± 1.3	14.0 ± 0.4	16.7 ± 0.4	18.3 ± 0.6	20.1 ± 0.4
Number (1988)	4	4	5	5	5	5
GROWING SPACE 10.51 m²						
Diameter (cm) 1958	3.4 ± 0.2	4.8 ± 0.3	7.8 ± 0.4	10.6 ± 0.3	12.8 ± 0.3	15.1 ± 0.2
Diameter (cm) 1988	9.1 ± 1.7	11.9 ± 0.6	15.6 ± 0.7	18.2 ± 0.7	21.5 ± 0.3	24.3 ± 0.8
Number (1988)	5	5	5	5	5	5
Height (m) 1958	6.3 ± 0.6	6.5 ± 0.2	8.9 ± 0.3	10.9 ± 0.3	12.3 ± 0.3	13.0 ± 0.2
Height (m) 1988	11.6 ± 1.3	12.7 ± 0.5	16.0 ± 0.4	17.3 ± 0.4	19.6 ± 0.8	19.6 ± 0.6
Number (1988)	3	4	5	5	5	5
GROWING SPACE 18.68 m²						
Diameter (cm) 1958	3.1 ± 0.1	5.2 ± 0.3	7.6 ± 0.4	10.1 ± 0.4	12.5 ± 0.3	14.9 ± 0.2
Diameter (cm) 1988	6.7 ± 0.6	12.0 ± 0.8	17.5 ± 0.6	20.1 ± 1.0	22.7 ± 0.6	25.0 ± 1.0
Number (1988)	4	5	4	5	5	5
Height (m) 1958	6.0 ± 0.4	7.2 ± 0.1	8.7 ± 0.3	10.4 ± 0.4	11.8 ± 0.8	13.5 ± 0.2
Height (m) 1988	7.4 ± 0.8	13.2 ± 0.8	16.8 ± 0.3	18.7 ± 0.5	19.1 ± 0.6	20.4 ± 0.9
Number (1988)	4	5	4	5	5	5

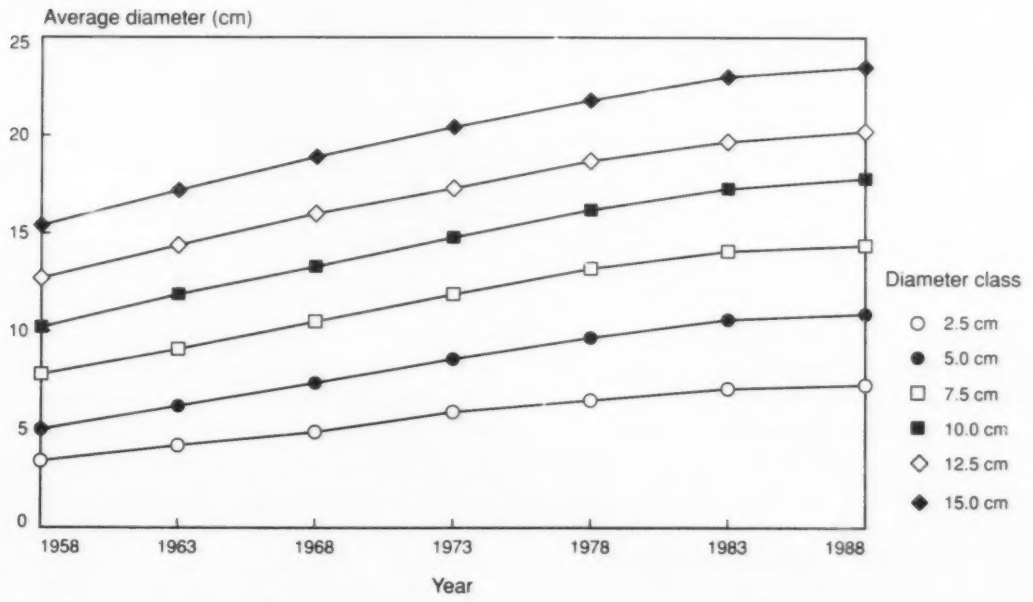

FIGURE 2. Effect of initial tree size on average diameter, for all treatments.

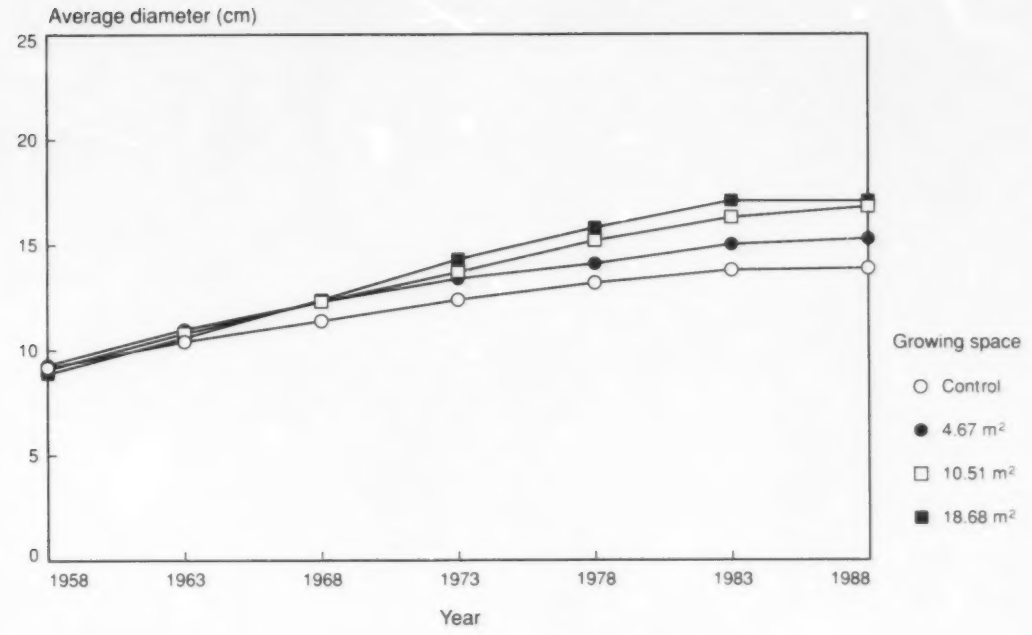

FIGURE 3. Effect of spacing treatment on average diameter, for all diameter classes.

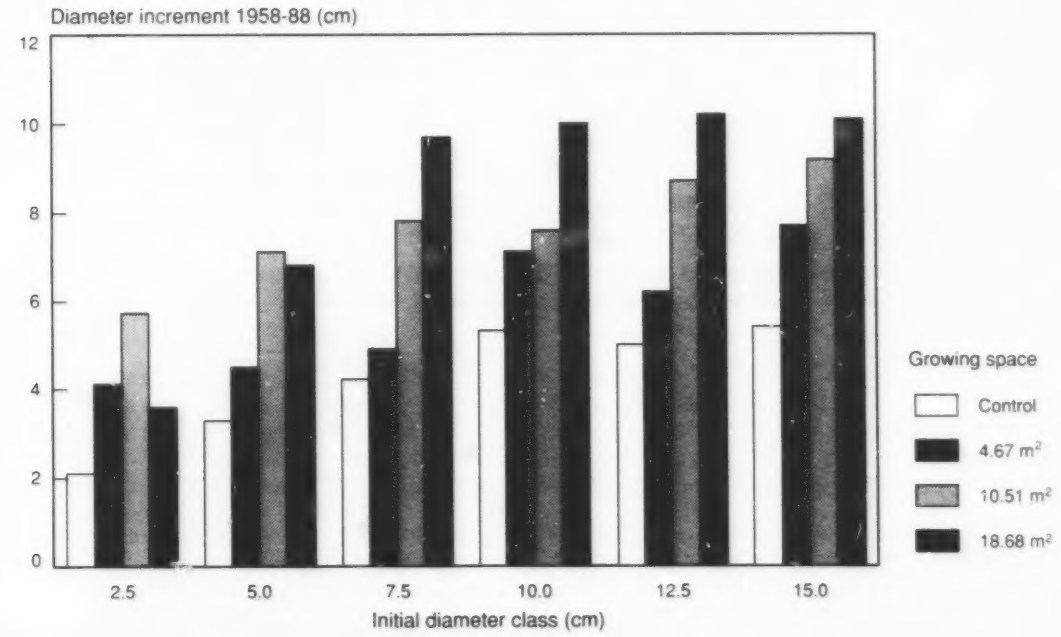

FIGURE 4. Effect of spacing treatment and initial size on average diameter increment.

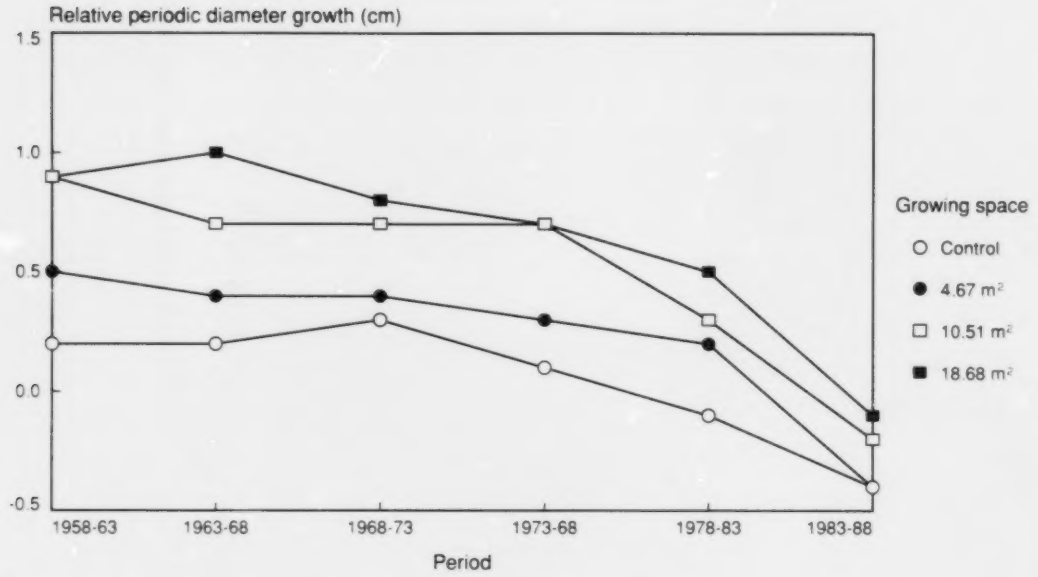

FIGURE 5. Periodic diameter growth relative to average diameter growth for each 5-year period of this study.

Diameter of the each crop tree was examined as a function of the diameter of that tree at the start of the 30-year period, the amount of growing space available, and the number of years since spacing. The resulting multiple linear regression was:

$$DBH = -2.810 + 0.216^{*}(TIME) + 1.215^{*}(DBH58) + 0.157^{*}(GS)$$

where:

DBH	=	diameter (cm) of the crop tree at year n
TIME	=	n years after spacing
DBH58	=	diameter (cm) of the crop tree at the time of spacing
GS	=	growing space (m^2) of the individual crop tree
R^2	=	0.939 Sy.x = 1.391 n = 687

All three independent variables made significant ($p \leq 0.05$) contributions to the model. The model provides a linear approximation for the period 5-30 years after treatment, and for trees in the range of 2.5–15 cm at the time of spacing.

Based on this relationship and a 30-year projection period, a 15-cm tree in 1958 in the widest spacing, will have a 2.6 cm larger diameter than in the unthinned control. Comparison with Table 1 shows that the model tends to overestimate diameter growth slightly in the control and underestimate growth in the widest spacing.

The Effect of Spacing on Height

In common with other studies (e.g., Schmidt 1978), this trial showed that height was only slightly affected by spacing over the range of densities studied. Although heights were measured every 5 years, they were reported and analyzed only every decade.

The average heights of the trees in 1958 and 1988, for each of the six initial diameter classes, are shown in Table 1.

The average height of the trees in the largest diameter class at the widest spacing increased by 6.9 m between 1958 and 1988. This compares with an increase of 5.2 m in the same diameter class in the control and 1.4 m for the smallest diameter class in the widest spacing. The increase in height appears to be greatest in the 7.5, 10.0, and 12.5 cm diameter classes (Figure 6).

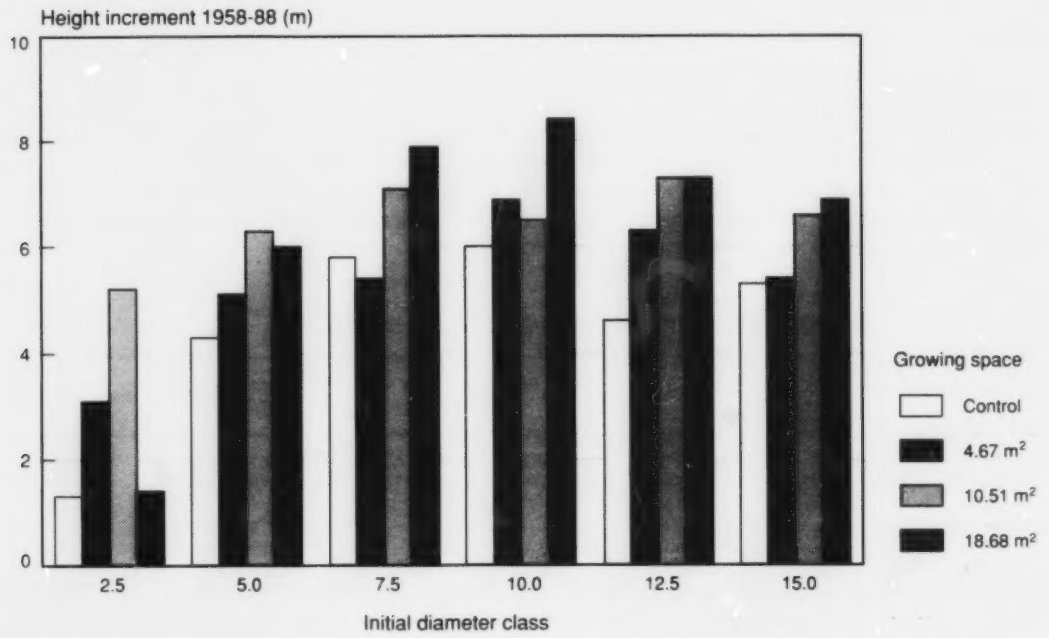

FIGURE 6. Effect of spacing treatment and initial size on average height increment.

The greater heights in the wider spaced trees are also accompanied by greater diameters. This relationship was examined by regression, with diameter, growing space, and time since spacing used as independent variables. The resulting multiple linear regression was:

$$H = 3.8348 + 0.0503^{*}(TIME) + 0.6631^{*}(DBH) - 0.0453^{*}(GS)$$

where:

H	=	height (m) of the crop tree
TIME	=	years since spacing
DBH	=	diameter (cm) at breast height
GS	=	growing space (m^2)
R^2	=	0.925 Sy.x = 1.09 n = 333

All three independent variables made significant ($p \leq 0.05$) contributions to the regression. The model provides a linear approximation for the period 10–30 years after treatment, and for trees in the range of 2.5–15 cm at the time of spacing.

Based on this relationship, a tree in the widest spacing and 20 cm in diameter has a predicted height in 1988 that is 0.7 m less than that of a similar sized tree in the control. The model tends to assign this reduction in height equally to all assessment periods, but the actual height difference appears to have increased over time. Comparison with Table 1 shows that the model tends to overestimate height for the smallest trees and for the largest trees in the widest spacings.

Although the relationship between height and diameter is traditionally curvilinear (Reinhardt 1983), a linear model is satisfactory for the range of the data tested in this study. Its use also avoids the problems associated with the selection of an appropriate curvilinear model for a relatively small diameter range.

The Effect of Spacing on Individual Tree Basal Area

The basal area of the average tree in each spacing level and for each measurement period is shown in Table 2.

The increase in basal area as a result of spacing was prompt and directly related to the level of spacing. The widest spacing level produced average tree growth that was about double that of a comparable tree in the control (Figure 7). These gains continued for the first 15–20 years but began to decline thereafter. As with diameter, the last 5-year period (1983-88) showed a dramatic reduction in the basal area growth in all treatments. The extent of this decline was such that in the last 5 years, the periodic growth rates of the closest (control) to widest spacings were only 26, 32, 52, and 54%, respectively, of their average periodic growth for the previous 25 years.

TABLE 2. Average basal area (cm^2) by treatment and year (mean ± SE)

	Control	Growing space 4.67 m^2	Growing space 10.51 m^2	Growing space 18.68 m^2
1958	80.6 ± 11.6	82.2 ± 12.7	79.1 ± 11.5	75.6 ± 11.0
1963	99.7 ± 13.5	111.2 ± 16.0	107.2 ± 14.8	105.8 ± 14.5
1968	119.4 ± 15.5	134.8 ± 18.9	136.3 ± 17.6	141.8 ± 18.4
1973	138.9 ± 17.6	160.1 ± 21.6	166.9 ± 20.2	182.8 ± 21.4
1978	157.2 ± 19.6	178.8 ± 23.7	202.5 ± 23.3	223.1 ± 25.3
1983	170.3 ± 21.2	201.4 ± 26.3	230.5 ± 25.2	257.9 ± 28.8
1988	174.7 ± 21.8	209.1 ± 27.2	245.9 ± 26.5	277.9 ± 31.7

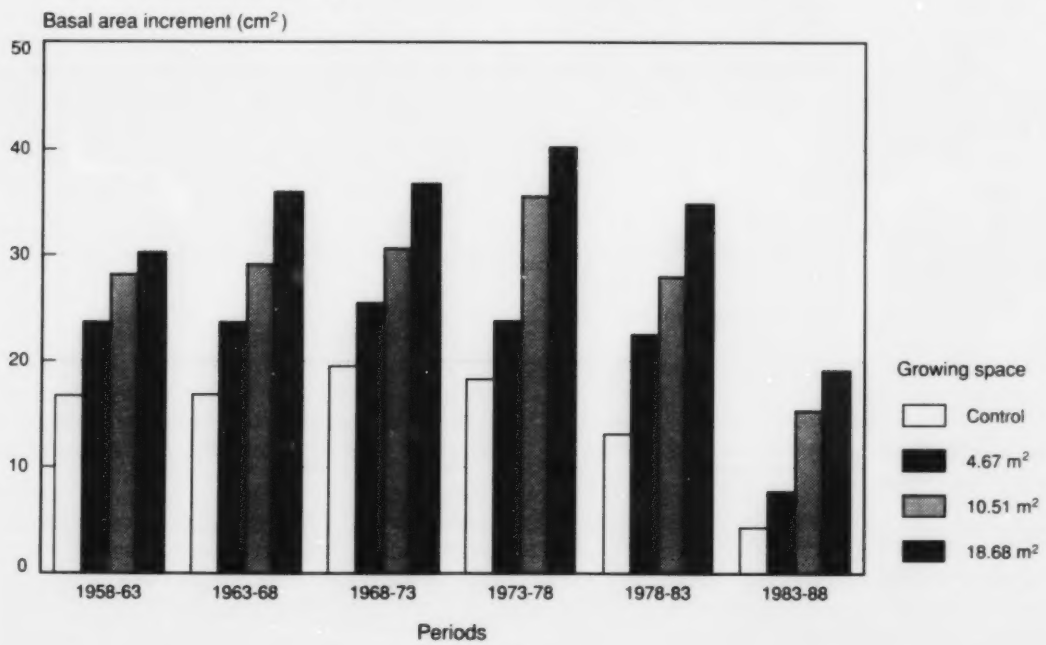

FIGURE 7. Effect of spacing treatment on average basal area increment for each 5-year period of this study.

The Effect of Spacing on Individual Tree Volume

Merchantable volumes (total volume inside bark, from a 0.3-m stump to a 10-cm top diameter) were calculated for each tree, greater than 10 cm DBH, with a variable exponent taper equation (Kozak 1988). The average merchantable tree volume is shown by diameter class and stocking level for each decade in Table 3.

TABLE 3. Average merchantable volume (m^3) per tree within each diameter class (mean ± SE)

	Diameter class (cm)					
	2.5	5.0	7.5	10.0	12.5	15.0
Control						
1958				0.004 ± 0.001	0.029 ± 0.004	0.079 ± 0.007
1968			0.003 ± 0.001	0.035 ± 0.007	0.077 ± 0.004	0.129 ± 0.010
1978			0.017 ± 0.007	0.082 ± 0.010	0.121 ± 0.008	0.189 ± 0.012
1988			0.035 ± 0.013	0.105 ± 0.013	0.141 ± 0.012	0.240 ± 0.021
Growing space 4.67 m^2						
1958				0.002 ± 0.000	0.032 ± 0.002	0.101 ± 0.006
1968			0.004 ± 0.002	0.037 ± 0.009	0.091 ± 0.009	0.193 ± 0.014
1978			0.019 ± 0.008	0.092 ± 0.016	0.145 ± 0.016	0.227 ± 0.022
1988		0.007 ± 0.003	0.036 ± 0.014	0.135 ± 0.019	0.192 ± 0.025	0.346 ± 0.026
Growing space 10.51 m^2						
1958				0.007 ± 0.002	0.033 ± 0.006	0.071 ± 0.003
1968			0.009 ± 0.002	0.054 ± 0.009	0.106 ± 0.005	0.170 ± 0.010
1978		0.004 ± 0.002	0.056 ± 0.010	0.115 ± 0.012	0.201 ± 0.013	0.276 ± 0.023
1988	0.032 ± 0.24	0.021 ± 0.010	0.101 ± 0.016	0.164 ± 0.016	0.268 ± 0.018	0.348 ± 0.033
Growing space 18.68 m^2						
1958				0.006 ± 0.004	0.028 ± 0.006	0.071 ± 0.004
1968			0.018 ± 0.005	0.057 ± 0.012	0.116 ± 0.009	0.173 ± 0.017
1978		0.024 ± 0.002	0.093 ± 0.011	0.146 ± 0.022	0.214 ± 0.010	0.288 ± 0.032
1988		0.028 ± 0.015	0.144 ± 0.014	0.223 ± 0.030	0.292 ± 0.017	0.387 ± 0.045

Merchantable volume increment increased with growing space. The average merchantable volume increment put on after 30 years by the trees in the widest spacing was 2.0 times that of the control, and 1.56 and 1.22 for the intermediate levels (Figure 8). Merchantable volume increment for the period 1958–1988 was also proportional to the initial diameter class (Figure 9). For the largest diameter trees, the average merchantable volume increment at the widest spacing was 0.316 m^3 over the 30-year period, compared with 0.161 m^3 in the control. Gains of this magnitude are repeated in the three largest diameter classes, with the widest spaced trees putting on twice the merchantable volume of the control trees. The more closely spaced trees, in the three largest diameter classes, produced proportionally smaller merchantable volume increments. In all but one treatment, trees in the smallest diameter class still had no merchantable volume.

This relationship was examined by regression, with initial diameter, growing space, and time since spacing used as independent variables. Preliminary models included initial height as an independent variable, but it proved not to be significant ($p \leq 0.05$) and was subsequently dropped. The resulting multiple linear regression was:

$$\text{sqrt(VOL)} = -0.8620 + 0.0098^{*}\text{(TIME)} + 0.2689^{*}\text{sqrt(DBH58)} + 0.0351^{*}\text{sqrt(GS)}$$

where:

VOL = merchantable volume (m^3) of the crop tree
TIME = years since spacing
DBH58 = diameter (cm) at breast height in 1958
GS = growing space (m^2)
R^2 = 0.8826 Sy.x = 0.0536 n = 307

All three independent variables made significant ($p \leq 0.05$) contributions to the regression.

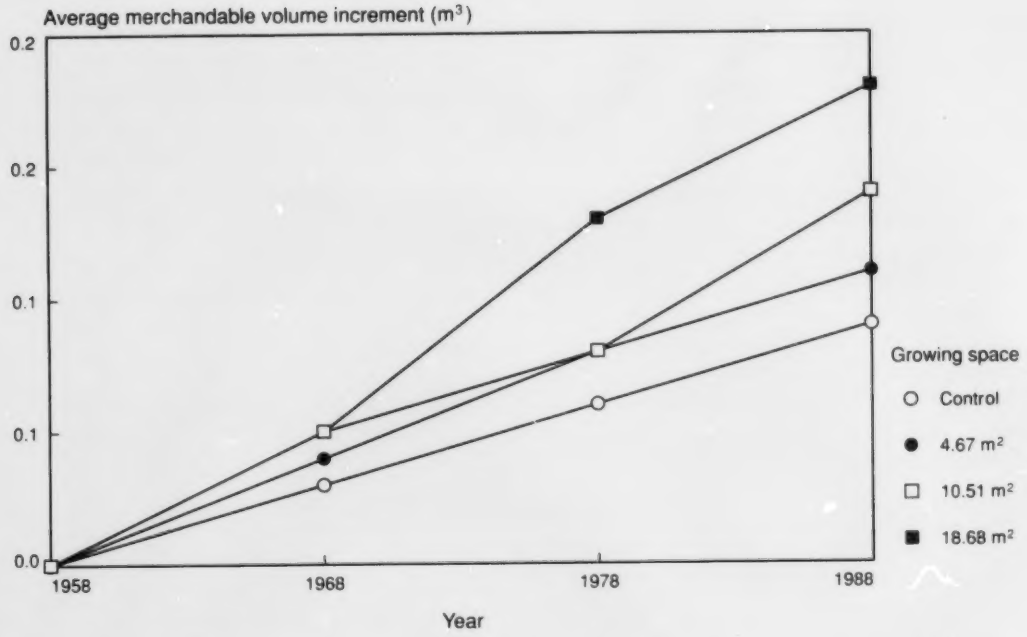

FIGURE 8. Effect of spacing treatment on average merchantable volume increment per treatment, by decade.

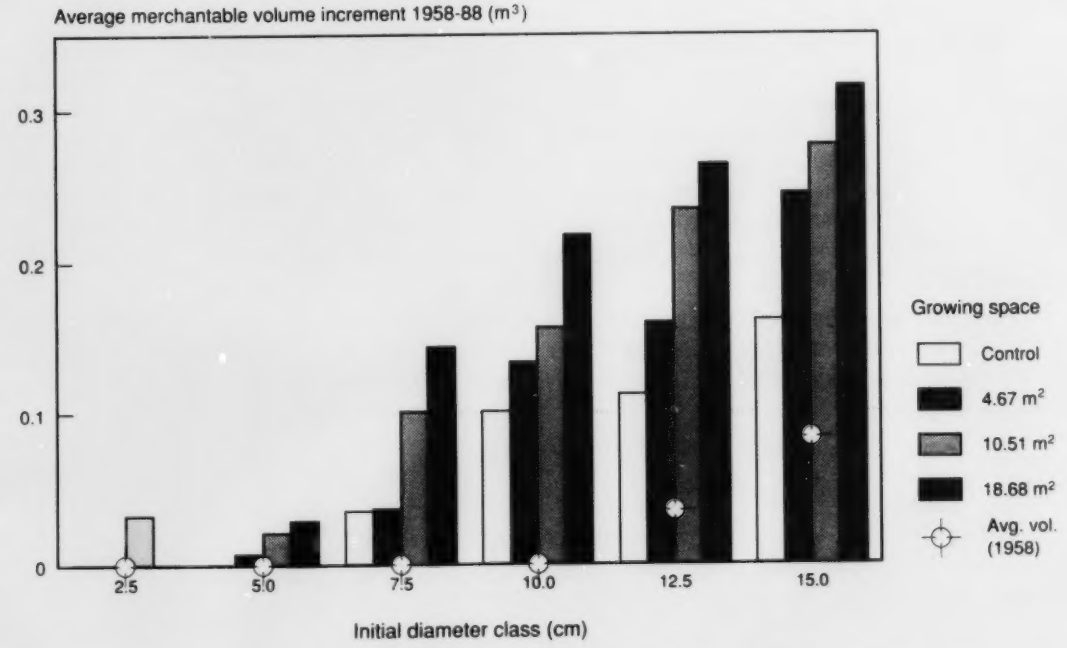

FIGURE 9. Effect of spacing treatment and initial size on average merchantable volume increment.

According to this relationship, a tree in the widest spacing that was 15 cm in diameter in 1958, would have a predicted volume in 1988 of 0.391 m^3. This compares with 0.272 m^3 for a similar sized tree in the control. Values for the intermediate spacing levels would be 0.302 m^3 and 0.345 m^3, respectively. The model provides a poor estimate for trees that are smaller than the merchantable limit (10 cm DBH).

DISCUSSION

Wider spacing produced a slightly lower height-to-diameter ratio. The reduced competition for the wider spaced trees presumably produced a reallocation of growth resources, benefiting diameter growth. This is not an unexpected response in a light-demanding species like larch. Although modelling the effect showed the contribution of growing space to be significant ($p \leq 0.05$) the actual difference was small (70 cm after 30 years). Thus, although the spaced trees are taller than their unspaced counterparts, it is largely due to the greater diameters achieved in the wider spacings. The altered ratio had little impact on merchantable volume.

Diameter responded promptly to spacing, and was proportional to spacing intensity. How much greater individual tree response could be obtained with greater spacing is unknown. The greatest spacing in this trial does not appear to have produced the maximum response, although Figure 3 suggests that the magnitude of the additional response would be reduced at wider spacings than in this trial. Schmidt and Seidel (1988) report further diameter responses at spacing levels greater than those in this study (approximately 20.2 m^2). In that study, the trees were 9 years old at the time of spacing. Even though our stand was older, there is no reason to suppose that greater diameter growth responses could not have been achieved at even wider spacings than we used in this study. The absolute magnitude of such potentially greater responses, however, would probably be less than that reported after 20 years by Schmidt and Seidel (1988).

Spacing response appears to have lasted for 25 years, after which the periodic diameter and basal area increments have shown a dramatic reduction. There are several possible explanations for this decline: 1) the drier climate in recent years may have slowed growth; 2) the trees may have exhausted the additional growing space provided them by the spacings (this is unlikely, however, since the reduced growth rates occurred almost simultaneously in all treatments); and 3) insect and disease agents may have reduced growth.

Moderate to severe defoliation by the larch sawfly (*Pristiphora erichsonii* [Hartig]) was reported in the study area in 1966 and 1967. The larch casebearer (*Coleophora laricella* Hbn.) has been observed annually in the study area since 1968. Defoliation in the area was reported to be light to moderate in 1978–1980 and in 1984–85. Larch needle blight (*Hypodermella laricis* Tub.) has also been reported in the study area during the period of this study, with moderate defoliation in 1983 and 1984 (L. Unger, Forestry Canada, pers. comm.). No observations were made on the study trees themselves. They were probably affected by the defoliators, but the magnitude of the attack is unknown.

The major cause of the decline is likely the larch casebearer, which increased its defoliation significantly after 1978. This corresponds with the beginning of the observed growth declines. Its effect would be aggravated by the other defoliators reported.

It is also possible that repeated defoliation by the larch casebearer has suppressed growth and thus masked the magnitude of other possible effects discussed above. Some of the decline might be due to other unidentified influences as well.

Increases in diameter and height as a result of spacing have doubled the merchantable volume on the larger trees in the widest spacing compared to the control. Diameter growth has declined in the last 5 years, more so in the control than in the wider spacings. This effect is expected to continue and increase both the relative and absolute merchantable volume gains shown by the wider spacings.

A major shortcoming of single tree studies is the absence of any area-based estimates. Cellier (1979) discussed other advantages and disadvantages of single tree studies. Advantages include the relatively small area required for single-tree studies, and thus the ease of ensuring site uniformity and the reduction in the amount of recording. Offsetting this is the problem of how to deal with the competition between the test trees and the surrounding untreated neighbours.

No statements can be made about stand response, because this experiment is a single tree design. However, in most classical area-based thinning experiments, wider spacing means fewer trees per hectare and results in increased individual tree growth which cannot compensate for the reduced number of stems. In a stand thinned at age 33 years and again at 43 years, Seidel (1982) showed that in spite of the greatest total volume yield being produced by the highest stand density (1140 stems per hectare), at age 48 years, the greatest total merchantable volume yield was in the widest spacing (126 stems per hectare). Similar findings come from a study, reported 10 years after spacing in an upper elevation, 10-year-old stand (Seidel 1984). A third study (Schmidt and Seidel 1988) showed that only by thinning at an early age (9 years) could the net basal area of a spaced treatment exceed that of the control (37 050 stems per hectare) after 20 years, and then only in the spaced treatments with 2200 trees per hectare or more. However, all of these studies were reported at a relatively young age, before the higher density treatments had reached a technical rotation age.

Cole's (1984) study of crop tree thinning differed from this one in that the radius of clearance was determined by the size of the crop tree, through the use of the "D+4" rule (removal of all trees within a radius in feet equal to the diameter of the crop tree in inches plus 4). Thus, for the largest trees in this study, the radius of clearance would have been midway between the lightest treatment and the medium intensity treatment, with a radius of about 3 m; smaller trees would have lesser spacing. A second difference between the two studies is the age of the stand when thinned — 50 years in contrast to the 31 years of this study.

In spite of the differences in design between the two studies, Cole's (1984) findings are similar to those observed in the present study. In both studies, significant increases in basal area increment were recorded, with the larger responses occuring on the larger trees. Overall response was less on the older trees. According to Cole's model, a 220-cm^2 tree would produce a 25 year basal area increment of 174 cm^2; the diameter model developed in this study would give a 25 year basal area increment of 240 cm^2 on the same tree, spaced to the same radius. Cole suggests that one of the reasons for the poor response was the 50-year age of the stand at the time of spacing. This interpretation is supported by the results of this study, where trees that were younger than Cole's gave a greater response. Further individual tree gains in both studies could probably also have been obtained if spacing were done more intensively.

The age of the trees at the time of spacing has a major effect on the magnitude and duration of thinning response. Schmidt (1978) reports spacing a 9-year-old stand of larch. In that study, trees that were approximately 1.3 cm in diameter and spaced to 3.3 m (approximately equal to the 10.51 m^2 treatment in this study) put on an additional 5 cm in diameter over 15 years, compared to the control trees. In our study, the gains by similarly treated but larger trees (3.4 cm) were 2.2 cm over the same period. The major difference between the two studies is the age of the trees at the time of spacing. Differences of this magnitude are largely due to the degree of crown lift that occurs at high densities in larch. For spacing to have its maximum effect on growth, it must occur before crown lift starts, or at least shortly after. This can be as early as 7 years.

At the time of spacing, photographs were taken of selected trees to monitor apparent crown expansion. Comparison with subsequent photographs showed that the majority of observable crown expansion occurred in the first 10 years after spacing.[4] For individual trees, the greatest amount of crown expansion occurred in cases where smaller (e.g., lower crown class) trees created a "hollow" spot in the live crown of selected trees, before spacing. These hollow spots filled in after spacing. The larger trees showed little or no crown expansion, probably because they were emergent dominants before spacing, and were thus experiencing little crown competition. Schmidt and Seidel (1988) show that crown length in larch declines rapidly with overcrowding, but can increase in spaced trees as a result of self-pruning proceeding at a slower rate than vertical elongation. Crown length probably did increase in the wider spacings in the present study and the growth responses obtained are likely at least partially due to increased crown length.

The continued gains in radial increment long after any apparent expansion in the crowns suggests that the increased growth is not solely due to crown release, and does in fact contain a considerable response to reduction in root competition.

[4] Thompson, 1984.

The results of this study show that larger diameter trees produce the greatest basal area increment, regardless of treatment. Schmidt (1966) showed that initially high stem density has a negative effect on average stem diameter at an early age. Similarly, Roe and Schmidt (1965) suggest that radial growth response to spacing is proportional to competition levels before spacing. In this study, all stems examined were approximately the same age in spite of dramatic differences in size. No record was made of stem densities at the time of spacing. Thus, the confounding effect of initial stand density remains to be investigated in study future studies.

CONCLUSIONS AND RECOMMENDATIONS

In this study, spacing had a minimal effect on height growth. Wider spaced trees were slightly but significantly shorter than trees of the same diameter in the control.

The major effect of spacing was on diameter, and therefore on basal area and volume growth. Response was prompt and varied directly with the degree of spacing. The diameter growth response was also proportional to the size of the tree at the time of spacing. No upper limit of response was detected from the range of spacing in this study. Also, growth response initially increased in all spacings, gradually declining after 15 years in some spacings, then dramatically declining after 25 years in all spacings. The cause of this decline is uncertain, but defoliation by the larch casebearer and other defoliators is the likely reason.

Comparison of the results of this study with those obtained elsewhere shows that at 31 years, these trees were too old for maximum response. Larch should be thinned early, before self-pruning starts. This could be as early as 7 years.

The results of this study are consistent with those of other spacing studies in larch. The larger trees produced the greatest growth response. Thus, in any spacing operation, preference should be given to the larger individuals that already demonstrate better growth. Wider spacing levels also increased growth, but the practitioner should be cautioned against spacing too wide. The spacing level at which volume per hectare is optimized will be lower than the level at which diameter growth is maximized. That point cannot be identified from a single tree study such as this. The level will also vary with the age and size of the stems at the time of spacing. Only if trees are spaced at an early age can volume growth be expected to exceed that removed in spacing (Schmidt and Seidel 1988). In older stands, such as this one, more conservative spacing levels will minimize the net volume loss, unless wider spacing and the accompanying larger individual tree size can be justified by premium prices for large stem sizes, significantly reduced harvesting costs, or improvements to other resource values such as ungulate habitat. If harvesting age is determined by average stem size, wider spacings may also be justified on the basis of a shorter rotation.

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